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TEST PROCEDURE FOR PAVEMENT CRACK FILLERS

Final Report

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16. Abstract

The purpose of the work reported was to investigate test procedures for bond extension tests for pavement crack fillers. A review of existing physical tests for crack fillers indicated a need for other than the standard AASHTO Test T187 and modifications made by researchers to the standard method. Two devices were built to test joints or cracks filled with sealants that have been used to keep water from entering a pavement system through surface cracks. Asphaltic concrete beams 12 x 5 x 3 inches in dimension were grooved and broken, and the grooves filled with sealants to serve as test specimens. The bonded beams were strained with two modes; one, under continuous elongation of the filler until failure occurred, and two, under a repeated tensile-compressive deformation until the joint was failed. Variables to the tests included temperature, dimensions of the groove, and amount of repeated deformation. Test results did not show a particular trend for the slow extensibility as affected by the ratio of width/depth (shape factor) of the joint. The extensibility at 32^{o} was generally less than at 77^{o}F. Some fairly good correlations were found between applied strain and the logarithm of repetitions of the repeated strain to cause failure. A method is suggested for setting specification values for sealants tested with the new methods. Continued experimentation with the repeated loading device would require a stronger (stiffer) construction for tests carried out at 32^{o}F.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

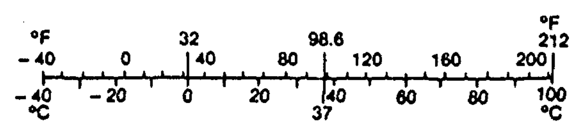
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
		AREA		
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
		VOLUME		
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement

(Revised April 1989)

TEST PROCEDURE FOR PAVEMENT CRACK FILLERS

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ABSTRACT

The purpose of the work reported was to investigate test procedures for bond extension tests for pavement crack fillers. A review of existing physical tests for crack fillers indicated the need for other than the standard AASHTO Test T187 and modifications made by researchers to the standard method. Two devices were built to test joints or racks filled with sealants that have been used to keep water from entering a pavement system through surface cracks. Asphaltic concrete beams 12 x 5 x 3 inches in dimension were grooved and broken, and the grooves filled with sealants to serve as test specimens. The bonded beams were strained with two modes; one, under continuous elongation of the filler until failure occurred, and two, under a repeated tensile-compressive deformation until the joint was failed. Variables to the tests included temperature, dimensions of the groove, and amount of repeated deformation. Tests results did not show a particular trend for the slow extendibility as affected by the ratio of width/depth (shape factor) of the joint. The extensibility at 32° was generally less than at 77°F. Some fairly good correlations were found between applied strain and the logarithm of repetitions of the repeated strain to cause failure. A method is suggested for setting specification values for sealants tested with the new methods. Continued experimentation with the repeated loading device would require a stronger (stiffer) construction for tests carried out at 32°F.

INTRODUCTION

It is generally accepted that all pavements will have cracks. These cracks may be designed into the system such as for portland cement concrete surfaces. Also, they may result from stresses imposed by traffic or from the partial constraint to volume changes caused by variations in temperature or moisture in the total pavement system. For other than aesthetic reasons, cracks in the surface of pavements are not tolerated because then water would have an access to the subsoils and weaken the pavement system. Generally, at first appearance and before there is a loss in structural integrity, these cracks are sealed to inhibit the entrance of surface water to the subsoils.

The materials used for the sealant must have rather special properties for resistance to the stresses imposed by the following conditions on a transverse crack:

1. Widening of the cracks due to cooling of the pavement.
2. Restrained shrinkage of the sealant due to cooling.
3. Shearing and bending stresses due to the passing of a wheel from one side of the crack to the other.
4. Shearing and bending stresses due to curling of the surface from gradients in temperature and moisture, and
5. Increasing effects by simultaneous occurrence of some of the above.

Additionally, the sealant must have good resistance to the adverse effects that come from weathering; that is, must have good durability for maintaining its desirable properties. Also the consistency of the material during warm weather must be resistant to the intrusion of surface grit that would restrict the closing of the crack during the higher temperatures.

For many years, the principal and standard test for use in specifying sealants for highway joints (cracks) has been AASHTO-T187. In particular, in this report we are concerned with the bond-extension test. The test has received adverse criticisms related to the following:

1. The length of time to complete the test is too long.
2. The sample dimensions.
3. The special mortar blocks bonded with the sample.
4. The loading condition is neither dynamic nor continuously repetitive.

There is a consensus in the reports reviewed in that all have suggested the AASHTO test method be modified or by implication, that it be changed to consider dynamic loadings.

BACKGROUND

The literature review for test methods to evaluate joint sealers indicated that in 1951 Federal Specifications SS-R-406c had an accepted Test Method 223.11 [1], and that ASTM had a similar procedure with Designation D1191-52T [2]. Robbers and Swanberg [3] refer to Federal Specification SS-F-336a, dated May 1947, that included requirements of sealants for pour point, penetration, flow, and bond. We did not find a description for that test method for the property of bond; however, the authors reported that it is a difficult and unsatisfactory test and may or may not represent service conditions. The 1959 report by Tons [4] on the testing of joint sealants also suggested that the bond-ductibility test procedure of the Federal Specification was not a particularly good one. That method had come through the years with only slight changes. A brief description of the present (1986) AASHTO procedure is given in the following paragraphs.

AASHTO Test Method T187-60-Concrete Joint Sealers [6] describes the procedure for making and stretching laboratory specimens. The hot sealant is poured between two specially prepared mortar blocks that are 3 x 2 x 1 inches. The sealant is centered on the 3-inch length and is 2 x 2 inches in cross section and 1-inch in width along the axially loaded direction. The standard test temperature is 0°F and the extension rate of the sealant is 1/8-inch per hour. The specimen is stretched for a distance of 0.5 inch for a 50 percent elongation and then stored at room temperature to return it by recompression to the original 1 inch dimension. The standard testing sequence is for 5 cycles. Failure of the specimen is defined as a crack (cohesive) or separation (adhesive) that is over one-quarter inch deep. The test method will not rate the relative performance of different sealants; it is simply a go/no go characterization of a specimen. An early investigator was Tons [4] who reported on the poor repeatability and reproducibility of the bond-ductility test. Several investigators have modified the original test method to yield results useful for the ranking of materials.

The 1959 report by Kuenning [5] presented data obtained from laboratory tests on joint sealants that were cast into portland cement concrete blocks 2-1/2 x 4 x 16 inches. The joint width was varied as well as the testing speed. Kuenning discussed the influence of "shape factor", that is, the width to depth ratio of the sealant on the severity of stress caused by the stretching o the sealant in the joint. He stated that the extensibility of a sealed joint " ... is not strictly an inherent property of the material, but is highly dependent on the relative dimensions of the cross-section of the sealer, referred to as the "shape factor". The influence of geometry or shape factor has been discussed by Tons [7] and also by Basha and Manke [8].

The Louisiana Department of Transportation conducted research on joint sealants which was reported by Kinchen et al. [9]. In this work, the authors reported on a new test method for joint sealants. The method with LDH Designation TR 609-76 was called The Bostick Mastic Tester. The seal was 0.5 x 0.5 x 2.0 inches and cast against concrete blocks 2.0 x 2.0 x 1.0 inches. The specimen was pulled and compressed in a direction normal to its 2.0-inch dimension. The specimens were subjected to alternate cycles of cooling while being stretched to reach a temperature of 0°F and an elongation of 65 percent, and then being compressed and heated to reach a temperature of 160°C and a compression of 35 percent. The complete cooling and heating cycle was completed in an eight-hour period. The cycling was continued until failure. Failure being reached when 15 percent or greater of the 2-inch length or depth had failed in adhesion, cohesion, or roping. The authors recommended that 40 cycles of the test be used as a measure of satisfactory laboratory performance.

A bond-ductility test was developed and reported by Basha and Manke [8]. The device for the test was used for research on asphalt sealants conducted for the State of Oklahoma's Department of Transportation in 1979. The test set-up and procedure were comparable to AASHTO Test T187, except that the sealants were used to bond asphaltic concrete blocks. The sealant sample had dimensions of 6 inches x 2 or 1 inch x 0.125 or 0.25 inch. The extension of the sealant joint was normal to the 6-inch dimension at a rate of 1/8-inch per hour, at a temperature of 0°F and to an extension of 100 percent relative to the 0.125 or 0.25 dimension. After stretching the sealant, the specimen was returned to room temperature and compressed to its original dimensions.

The sealants were mainly asphalt cement, cut backs, and asphalt emulsion. The liquid asphalts were evaporated prior to making the bond-ductility specimen. Only the cured cutbacks were able to withstand more than one cycle of stretching and compressing; these ranged from 2 to 10 repetitions.

Barksdale and Hicks [9] reported on research for improved concrete pavement-shoulder joint design. In this work several variables were used following modifications to the conventional five-cycle bond test of AASHTO T187. A special bond test device with cycling capability was built and test variables included bonding blocks, specimen size, amount of extension, strain rate, and artificially weathered sealants. All treatment effects were based on passing a five-cycle stressing at $0^{o}F$. Two significant findings reported were that specimen size (shape factor) did not have a significant effect on laboratory performance and that the rapid rate of tensile deformation rate was a very severe condition of loading. It is noted that the lack of effect due to a shape factor was contrary to the findings of Kuenning [5] and Tons [7].

The review of the above reports has shown that the bond-extension test of AASHTO T187 was not considered a good one for evaluating crack sealants. Objections and shortcomings to the procedure were that the testing period was too long, it had a pass-or-fail result, it did not stress in the compression mode, and it was not really a repetitive or dynamic loading type of test.

Those thoughts were summarized by Cook and Lewis in NCHRP Report 38 [11],

> "The current specifications for highway sealants generally contain bond-extension test as the only performance

requirement. More tests are needed to make the specifications effective. An adhesion test, a compression-extension cycle, an incremental extension test, and a stress-relaxation should all be investigated."

The rest of the report is concerned with the testing of crack sealants under a slow extension continuous deformation and also under a fast repetitive (210 cpm) compression-extension deformation.

WORK DESCRIPTION

The research program was developed around a repeated loading device that had been built for a study of strain attenuating layers in asphaltic concrete construction [11]. The device was capable of exerting a displacement value that was set with a variable pitch cam and repeated at a relatively fast rate. A photograph of that device is shown in Figure 1.

The flow diagram of Figure 2 details the sequence of testing. As indicated, all of the sealants were stretched at a slow rate of 1/8-inch per hour and the six samples that had the largest percentage increase in joint width were used for additional testing. The additional testing consisted of slow continuous extension and also repeated extension-compression at a rapid rate. Both types of tests were performed at variables of joint shape and/or test temperature.

Materials

The materials used in the investigations were the sealants listed and described in Appendix A and asphaltic concrete obtained from a local hot-mix plant operated by the Tanner Company. The sealants were principally of the hot-pour type and the majority were of an asphalt-ground rubber combination.

The asphaltic concrete was a standard mix made to meet state, county, and city specifications. Its gradation would classify it as a 1/2" mixture with 5.6 percent asphalt. A large quantity of the hot mixture was obtained from the plant and separated into sample sizes to make more than the planned number of test beams.

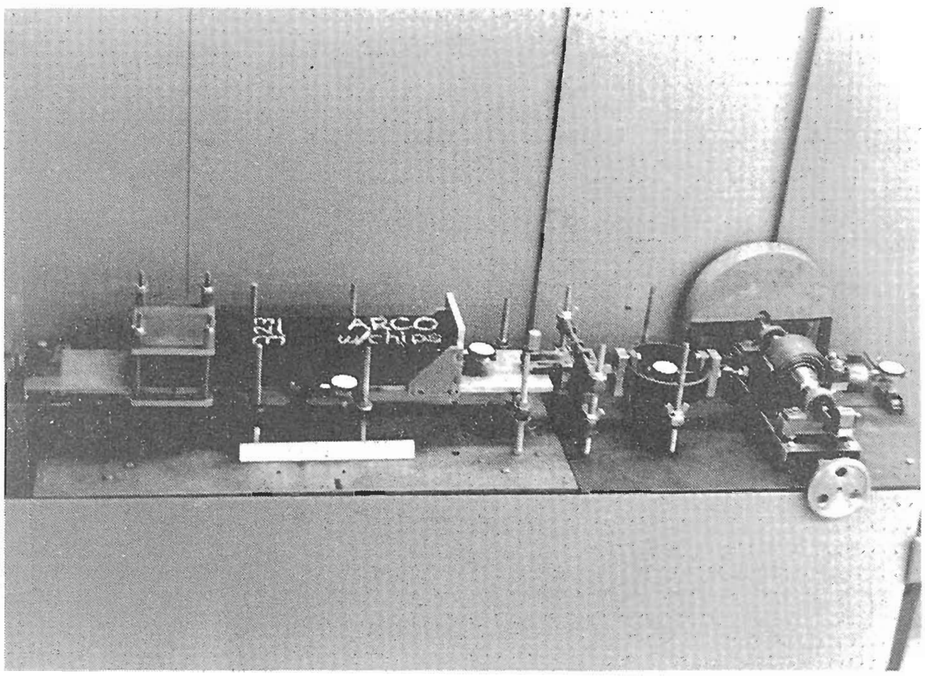


Figure 1. Setup for the Repeated Horizontal Shear Test.
Reference [12]

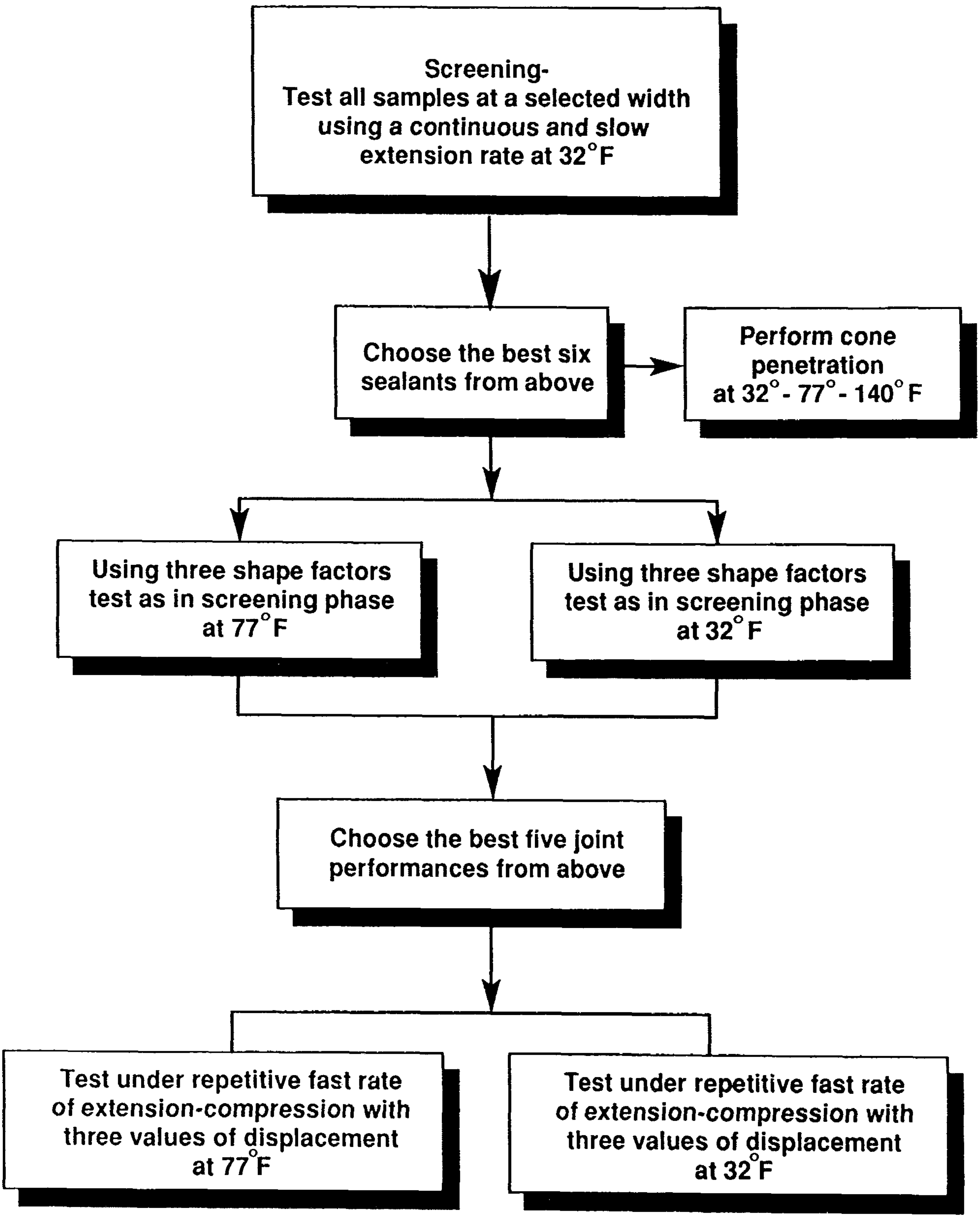


Figure 2. Research Plan

These samples were stored until needed and in this way the mixture was heated only once more to be compacted. The procedure for sampling and storing the mixture had been found acceptable for minimizing mixture variability as determined in earlier research [12].

Test Methods

Making Beam and Forming Joint

The test specimens consisted of asphaltic concrete beams 12 x 5 x 3 inches that were compacted with a vibratory kneading compactor (VKC). The procedure for making a beam is given in Appendix B and also was described in Reference 12. The beam formed had a density that was at least 95 percent of that obtained with the VKC for a standard 4"D x 2-1/2" H specimen. However, no density measurements were made for these beams.

After the beam had been made for a couple of days, it was sawed to make grooves at midspan and on the five-inch faces. The beam was broken at the center span location and dried prior to filling one of the grooves with a selected sealant.

We recognize differences between the laboratory joint and one that would be found or formed in the field. These differences would be:

1. The aggregate in the joint would have a flat and uncoated surface to improve adhesion of the sealant.
2. The sealant was flush with the top of the asphaltic concrete.

3. The sealant was bonded to the bottom of the groove but did not penetrate into the crack.

The second groove was filled with the sealant after the first one had been tested so that a new groove was used for each test of the sealants.

<u>Slow Extension Test</u>

The procedure for the slow extension test is given in Appendix C. A photograph of the test set-up is shown in Figure C1. The rate of extension used was 1/8 inch per hour and continued until the sealant had failed by either adhesion to the groove or by cohesion within itself. The base plates to the beams rested on rollers to minimize restraining forces on the beam-plate assembly. Tests were performed at 77°F and 32°F.

<u>Rapid and Repeated Extension Test</u>

The test procedure described in Appendix D was established after obtaining unexplainable and inconsistent results when testing at 32°F. The testing at 77°F yielded rather consistent and expected data. The lack of repeatability of results in the 32°F test appear to have been caused by the type of stress or the direction of deformation applied with the first rapid loading of the sealant. If the first loading were one of extension or tensile stress, then the joint would be damaged. The problem was solved by assuring that the first rapid loading at 32°F was one of compression.

<u>Penetration Test</u>

The resistance to intrusion of pavement surface grit into the sealant was determined with AASHTO Test T49 [6]. For the purpose of this characterization, the standard needle was replaced with a penetration cone confirming to the requirements given in ASTM Test D217. The test was performed at temperatures of 32°, 77°, and 140°F.

TEST RESULTS AND DISCUSSIONS

The general discussion of the test results will be centered about the capabilities of the test to differentiate the responses from the various sealants and to obtain a measure of reliability of the test methods. The results of the tests are shown in the tables of Appendix E and culled data will be presented in this section.

Penetration Tests

The cone penetration test data shown in Table E1 indicates that all of the sealants made with asphalt cement and rubber (3a-3g and 4) met specifications set by AASHTO [13]. This specification requires that penetration at 77°F be less than 90; sample 3e was formulated to meet a different set of specifications.

At the lower temperatures the cone did not penetrate sample 1 since the tip left no hole nor was it wet upon recovery.

Samples 2 and 5 were too soft to have distinctive penetration values at any of the test temperatures. As expected, sample 2 (an emulsion) and sample 5 (a cutback) would not be expected to have any resistance to penetration by the weighted cone. If standard requirements were that the penetration value at 77°F be less than 90, then it would seem that samples 1 and 3e would be the least desirable of those that could be evaluated with the test. It will be shown that these two were the better performers in the slow and rapid-repeated extension tests.

Slow Extension Tests

Screening Test

The eleven samples that had been selected for evaluation were screened with a slow rate of joint extension at a temperature of 32°F. The rate of stretching of the sealant was at 1/8 inch per hour and the joint had dimensions of 5 inches long by 0.5 inches deep and a width of 0.2 inch. The shape factor of the joint, that is, width over depth, was thus 0.2/0.5 or 0.40.

Table E2 in Appendix E shows the results of the screening test. The response is shown in terms of percentage of elongation since the joint width was not always exactly 0.2 inch. Examination of the ranking of these samples shows that numbers 3c, 3a, 1, 3e, and 3d were the top five performers and that these had failed by adhesion to the face of the joint. These five sealants, plus 3f, were chosen for further testing six samples as indicated in Figure 2.

Shape Factor Evaluation

The sealants selected from the screening test were then used to examine the effects of shape factor on the results of the slow extension loading at temperatures of 77° and 32°F.

The purpose of the research was to evaluate the test methods and sealants and not necessarily joint design. As a consequence, the joint to be used in further testing should be one to severely stress the sealant and result in failure within some acceptable time period. The shape factor for the initial testing was 0.4 and the failure of all six sealants was by adhesion. According to theory, increasing the width of the joint would decrease the cohesive stressing and increasing the depth would decrease the adhesive stress. In combining these effects, it was decided to increase the joint width to 0.30 inch and vary the depth to 0.5, 0.6, and 0.7 inches to evaluate the effects of the shape factor.

Table E3 in Appendix E shows the results of the tests performed to evaluate the shape factor effects on resistance to slow extension. Figure 3 is a more visual representation of these data to show shape factor effects and performance of the sealants to the test. From the figure, it is evident that the shape factor did not have a consistent effect on performance. The shape factor did not seem to have any effect for the 77°F testing and for testing at 32°F the effect was not directional with reference to shape factor values. Except for sample 3f, all of the failures were of the adhesive type. Table E3 shows that the failures for sample 3f were split between adhesive and cohesive. The most notable effect was that of temperature. Figure 3 shows that the failing elongational strains at 32°F were at least twice those obtained at 77°F. We can only surmise that these differences were due to the higher viscosity of the sealant at 32°F and also to the tensile prestressing of the sealant caused by constraint and reducing its temperature to 32°F.

Rapid-Repeated Extension-Compression Tests

Following the slow extension testing, the sealants were evaluated for resistance to rapid-repeated tensile strains -- a type of fatigue testing. This test could be thought of as

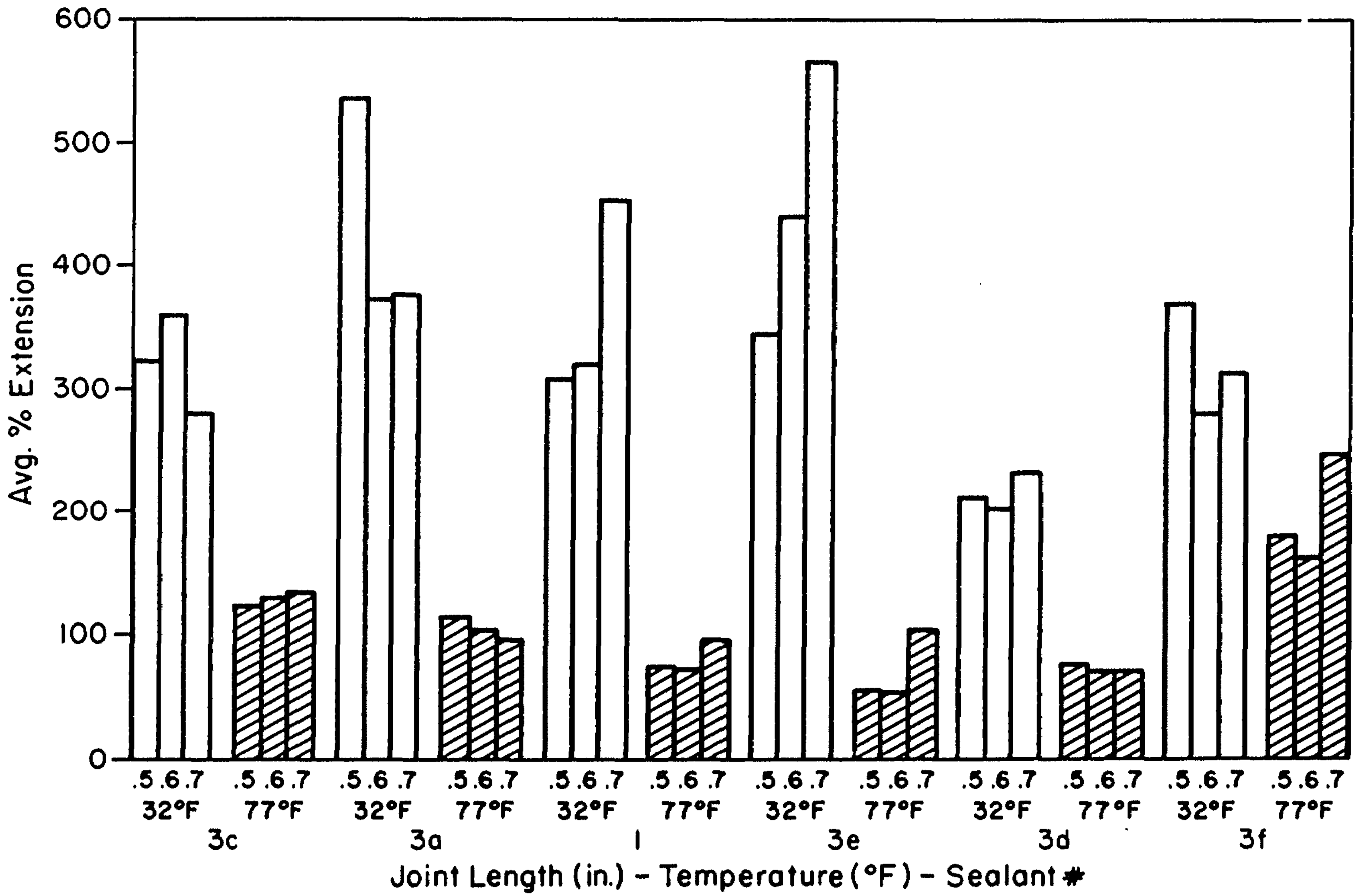


Figure 3. Effects of Shape Factor and Temperature on Response of Sealants to Slow Extension Test. Joint width of 0.30 inch.

simulating effects due to the staining caused by truck traffic. Basha and Manke [8] reported that the deformation of joints caused by trucks were about ten percent of those caused by temperature. Although the extensions or strains shown in Table E3 were for failure conditions, ten percent of a total average was considered in setting the strain values for the repeated loading tests. Table E4 show the number of tension-compression cycles to cause failure by set strains for the five sealants. The results of regression analysis are shown in Table E5 for the model

$$\epsilon = I_o + b \log N_f$$

where:

ϵ = strain

N_f = number of repetitions to failure

I_o and b = constants

The results of the regression analysis shown in terms of t and R^2 values indicate that the chosen relationship between and N seemed to define adequately the fatigue life of the joint fillers.

Figure 4 presents plots of the fatigue life equations developed for testing the sealants at 77°F and also at 32°F. From Table E4 and Figure 4, it is apparent that sealant 3e had the best resistance to the repeated test, especially at a temperature of 32°F. However, the rating of these sealants or others that would show the diversity of curves, would be difficult to establish on the basis of equation constants. The ranking of performance of the sealant can be set by comparing values of repetition to failure for a fixed amount of strain. For example, assuming a strain of 10

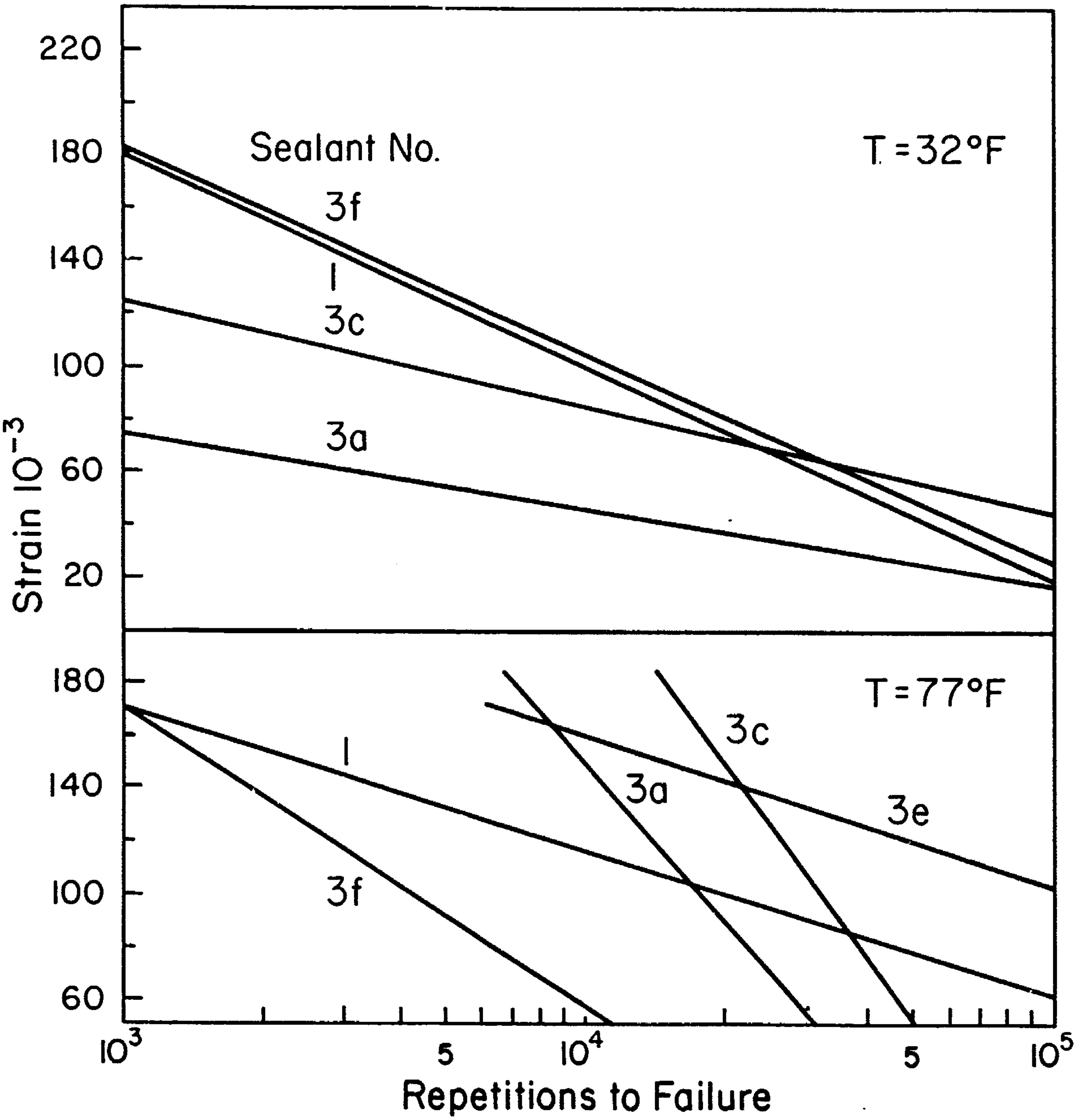


Figure 4. Relationships between Repeated Strains and Number of Repetitions to Cause Failure of Sealants.

percent for testing at 77°F, the ranking of the five sealants would be as follows:

Ranking	1st	2nd	3rd	4th	5th
Filler No.	3e	3c	1	3a	3f

GENERAL DISCUSSION

It is interesting to note that the ranking of the sealant by the slow extension screening test was quite similar to that for the rapid-repeated test. Those ranking are repeated for ease of comparison:

Ranking	1st	2nd	3rd	4th	5th	6th	
Filler No.	3c	3a	1	3e	3d	3f -	slow test at 32°F
	3e	3c	1	3a	3f	-	rapid test at 77°F

The ranking of the sealants' performance as shown above seem to give a general relationship; but that by itself, would not serve to set minimum requirements for performance conditions. Although the data are quite limited, they will be used to demonstrate a reasoned method for using the test results to set purchase specifications.

Penetration Test

The cone penetration values met the usual requirement of less than 90 as set for testing at 77°F for those materials that would have been thus formulated. These standard requirements as set by AASHTO would be accepted. However, it is interesting to note that if the intent of the penetration test is to control the softness of the material to minimize intrusion of surface grit into the filler, then why not specify the test temperature to be 140°F? Samples 1 and 3e had the highest penetration values when tested at 140°F, yet these two had the best performance or resistance to the extension tests.

Slow Extension Tests

Specification limits for this test were selected after study of the rapid-repeated extension-compression tests. The joint would be set at a depth of 0.5 inch and a width of 0.375 inch. Limits of strain or percentage elongation would be as follows for two test temperatures:

1. At 77°F, a minimum strain of 0.80.
2. At 32°F, a minimum strain of 3.00.

Examination of Figure 3 shows that sample 3d fails this requirement.

Rapid-Repeated Tests

The fatigue life equations obtained from the regression analysis were used to calculate the number of repetitions to cause failure at 5 and 10 percent strain. This selection was based on a joint 0.375 inch wide and 0.50 inch deep and assuming that within comparable shape factors (if this is an influence) that these strain levels correspond to traffic strains that have been correlated to temperature failure strains. The listing of failure repetitions at those strain levels calculated for temperatures 77° and 32°F are shown below:

Sealant No.	3e	1	3c	3a	3f
N_f for 5% strain, 77°F, 10^3	718	164	54	29	11

Sealant No.	3e	3c	1	3a	3f
N_f for 10% strain, 77°F, 10^3	100	33	21	17	4

Sealant No.	3e	3c	1	3a	3f
N_f for 5% strain, 32°F, 10^3	∞	74	47	42	7

Sealant No.	3e	3c	1	3a	3f
N_f for 10% strain, 32°F, 10^3	∞	11	10	10	0.2

Examination of the number repetitions to cause failures at 32°F shows a definite difference for sealant No. 3a. As a consequence, we would require that minimum repetitions for failure at 5 and 10 percent strain be equal to 40,000 and 10,000, respectively. Additionally, from a similar review of the data for the temperature of 77°F, we conclude that the corresponding minimum number of repetitions be 25,000 and 15,000.

Combined Requirements

A summary of the performance of the six sealants with reference to the outlined requirements is shown below:

Sealant No.	Penetration	Slow Extension 77°F	Slow Extension 32°F	Rapid Extension 77°F	Rapid Extension 32°F
1	Pass	Pass	Pass	Pass	Pass
3a	Pass	Pass	Pass	Pass	Fail
3c	Pass	Pass	Pass	Pass	Pass
3d	Pass	Pass	Fail	N.A.	N.A.
3e	Pass	Pass	Pass	Pass	Pass
3f	Pass	Pass	Pass	Fail	Pass

The examination of the above tabulation shows that sealants nos. 3a, 3d, and 3f failed to meet the suggested requirements. As mentioned earlier, the procedure and numbers used are to serve as a possible model for writing a specification based on the tests used.

CONCLUSIONS

The amount of testing done for this program is considered to be somewhat limited in number. Under this situation, one must consider that the results and conclusions apply only to the materials and interpretation of the test results obtained for this study. Additionally, and equally important, the new devices used must be considered as pilot models both in terms of construction and operation. Some of the conclusions listed below are not based on numerical measurements but rather on observation of the operational procedures. Also, the remarks are addressed principally to the two new tests.

1. The review of the related literature indicated a continuing concern over the testing of crack fillers not meeting the desires of the authors.
2. The making of the test specimens was a rather simple procedure and the dimensions of the joints could be varied to control the amount of repeated strain utilized.
3. The joint construction did not simulate a field condition since the groove was sawed and the crack below the groove was sealed. However, this is not considered as a negative factor.
4. The device for the slow and continuous extension tests was found to be adequate for testing at 77° and 32°F.
5. The device for the rapid-repeated tension-compression tests was found to be adequate for testing at 77°F;

however, it seemed to need structural stiffening for the testing at 32°F.

6. Careful attention to setting up of the repeated loading of the specimen was required to assure that the first rapidly applied stress was of the compressive mode. It was reasoned that a tensile stress applied first and rapidly applied at 32°F would damage the joint due to the brittleness of the sealant.
7. A disadvantage of the new test devices is the need of a walk-in freezer room.
8. The joint shape factor did not have a consistent effect on performance of the slow extension tests.
9. A fatigue life model for the sealants tested under repeated strains was found to be adequately described by $\epsilon = I_0 + b \log N_f$.
10. A suggested specification is given in terms of penetration values, slow extension strains, and number of repeated strains.
11. The best performers in the tests were the two elastomeric sealants, 1 and 3e, and sealant 3c.
12. Continuation of the investigation should be dependent on evaluation for feasibility of implementation by the sponsors.

APPENDIX A

IDENTIFICATION OF CRACK FILLERS

TABLE A1. IDENTIFICATION OF CRACK FILLERS

Laboratory No.	Trade Name	Comment
1	Super Seal 444	Elastometric - hot pour 285°F
2	CRF	Emulsion - cold pour
3a	Roadsaver 211	Hot pour at 380°F
3b	Roadsaver 213	Hot pour at 380°F
3c	Asphalt Rubber Plus	Hot pour at 380°F
3d	Roadsaver 221	Hot pour at 380°F
3e	Roadsaver 231	Elastometric - hot pour at 380°F
3f	Asphalt Rubber - AR2	Use at 0° - 100°F
3g	Asphalt Rubber - AR4	Use at 30° - 105°F
4	ARM-R-Shield CF-1326	Rubberized, hot pour 380°F
5	MC-860 plus Rubber	ADOT development

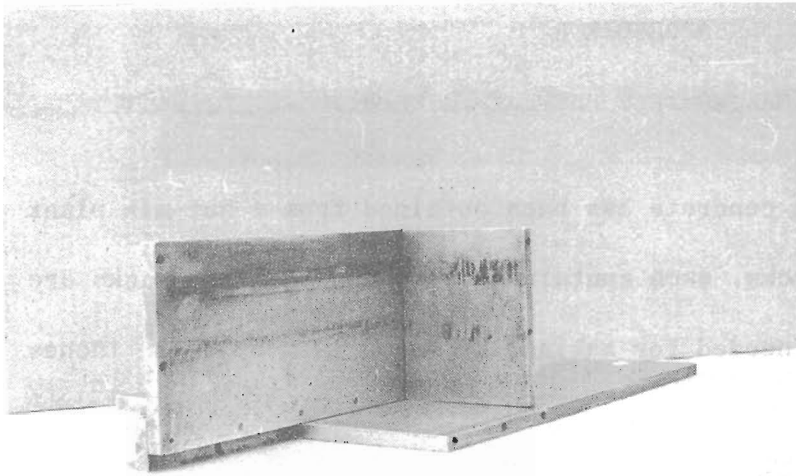
APPENDIX B

PROCEDURE FOR MAKING TEST BEAM AND FILLED JOINT

Note. A supply of asphaltic concrete has been obtained from a hot-mix plant and separated into paper sacks, each containing 15 pounds. These sacks are stored in a 77°F room until needed for making the beams 12 x 5 x 3 inches (L x W x H).

COMPACTING

1. Place pans of the mixture in 250°F forced draft oven until ready for compaction at that temperature.
2. Assemble beam molds and give a light coat of SAE 10 motor oil to the vertical interior surfaces. See Figure B1(a).
3. When the mixture in the oven has reached 250°F place a strip of paper 12 inches long by 5 inches wide inside the mold. Now introduce approximately one-half of the hot mixture into the mold in a uniform thickness of layer using a steel spatula spade between the mixture and the mold to minimize surface voids. The layer is then rodded 25 times using a bullet-nose 3/8-inch diameter by 18-inch long steel rod. Fifteen blows are given around the beams periphery and the remaining 10 within the interior of the beam. The rod holes are filled by raking the surface. The loose mixture is given an initial compaction manually with a steel tamping foot 5 x 4 inches. A strip of heavy paper (Kraft) 5 x 12 inches is placed on the mixture and then a steel plate 12 x 5 x 0.090 inches is placed on top of the paper strip. All of this is done as quickly as possible.



a. Partial Mold for Asphaltic Beam

b. Vibratory Compaction of Beam

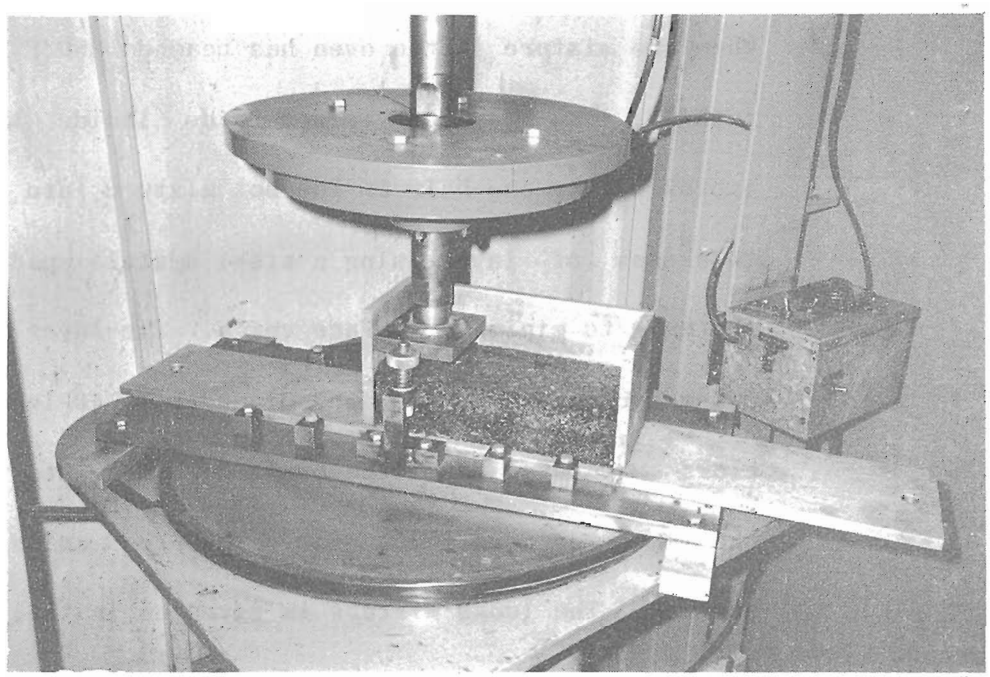


Figure B1. Setup for Making Asphaltic Beam

4. The beam mold is placed within the guides on the vibratory kneading compactor (VKC). See Figure B1(b). The compactor foot (5 x 4 inches) is lowered onto the asphaltic layer and then the compactor is energized. Be sure the turntable is not rotated, and that the loader is operating with 4 discs and at a frequency of 1200 rpm. The beam mold is manually moved back and forth 8 inches for 4 minutes at a rate of eight cycles per minute. Observe the surface of the beam so as to minimize differences in thickness along its length. The beam is removed from the VKC and the steel plate and paper strip are taken out. The surface of the beam is scored with a blunt screwdriver to keep from developing a compaction plane and aid in bonding the second layer. The second layer is placed and compacted in the same manner as the first one.

5. Following the vibratory compaction, the beam-mold assembly is removed from the VKC. The steel plate and paper strip are taken out and an I-beam ram 5 x 12 inches is placed on the beam inside the mold. The top surface of the beam is leveled with a universal testing machine and the application of 18,000 pounds (300 psi) held for two minutes.

6. The beam is taken out of the mold and stored at 77°F for at least one day prior to grooving and breaking.

SAWING

7. The beam is to be grooved along the 5-inch width with a diamond tipped masonry saw that is water cooled.

8. Mark the center line of the beam with chalk and place it on the sliding carriage of the saw. Adjust and fix the position of the blade so that it will cut to the desired depth, e.g., 0.5-0.7 inches. The depth of cut should be made in one pass of the blade.

9. The desired width of joint is obtained by moving the beam sideways to the saw blade.

10. Repeat the grooving process on the opposite side of the beam.

11. After grooving top and bottom of the beam, it is broken at the center using a cantilever arrangement at room temperature.

FILLING

12. Prior to filling the grooves, the broken beam is placed in a 140°F oven for a minimum of 15 hours. The groove must be clean and dry to maximize the bonding of the sealant to the cut faces of the joint.

13. See Figure B2 for a sketch of the beam and aluminum base plates set-up.

14. Connect two aluminum base plates with holding bars and attach the back and adjusting braces to the plates.

15. Place the broken beam on the base plates with the cracks aligned vertically.

16. Separate the two halves to place a piece of waxed paper between them. The waxed paper should be sized to just cover the broken surface. Manually press the two portions together. The waxed paper is to prevent healing of the cracked faces as these are pressed together.

17. Bolt the clamping plates loosely to the base plates.

18. Close the crack by hand tightening the adjusting brace bolt and then tighten the clamping plates.

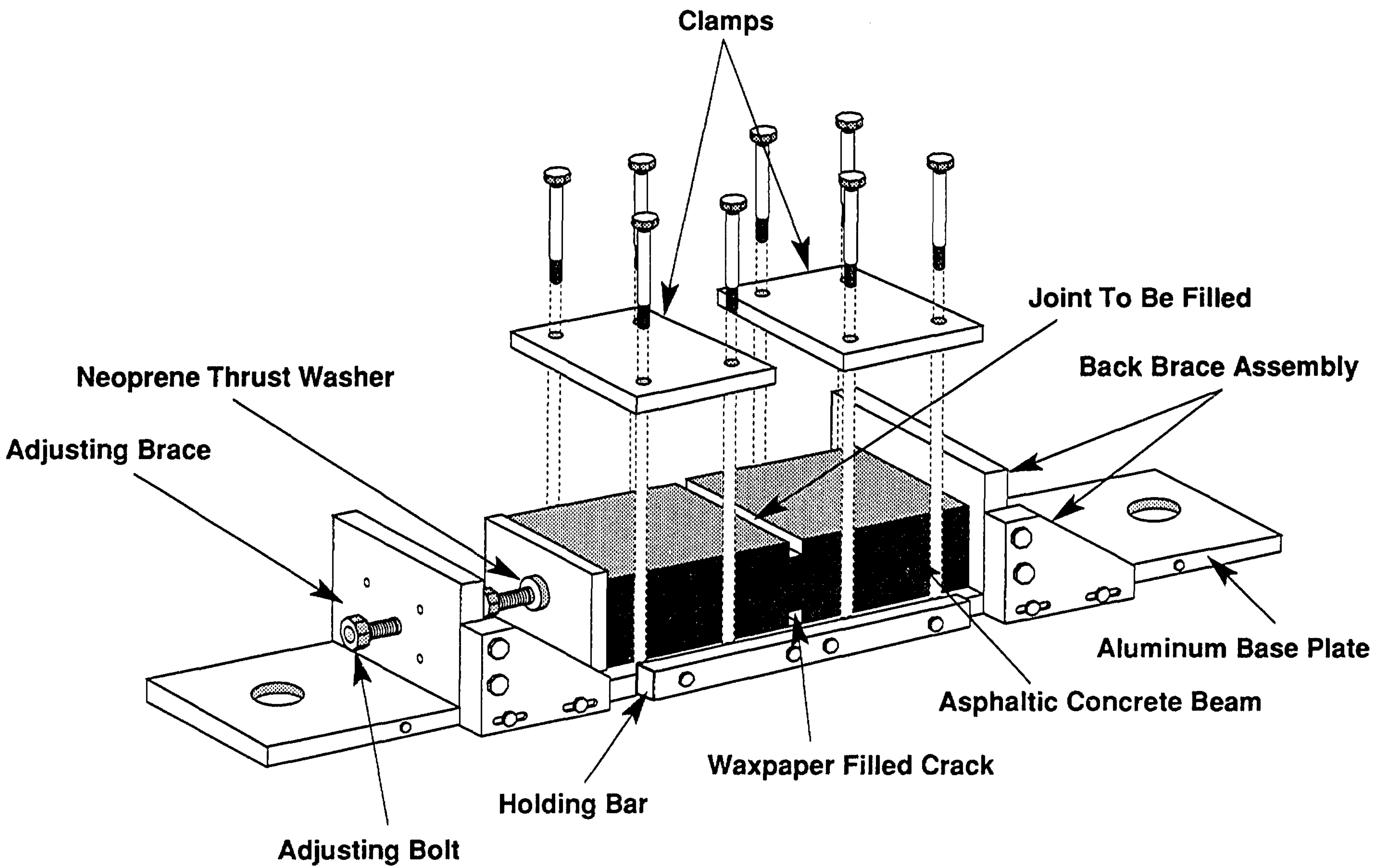


Figure B2. Schematic Drawing of Beam Setup for Filling Joint.

19. Use 3/4 inch masking tape to contain the sealant in the groove. Close the ends of the groove and place along the top edges of the groove to control the top width of the sealant. No tape is placed at the bottom of the groove since the crack has been sealed with the waxed paper.

20. The sealant at the proper temperature or consistency is introduced into the groove. Slight overfilling with hot sealant may be necessary to account for shrinkage. If the cooled sealant is above the beam surface, then use a hot steel spatula to trim off the excess. After the sealant has set, peel off the masking tape.

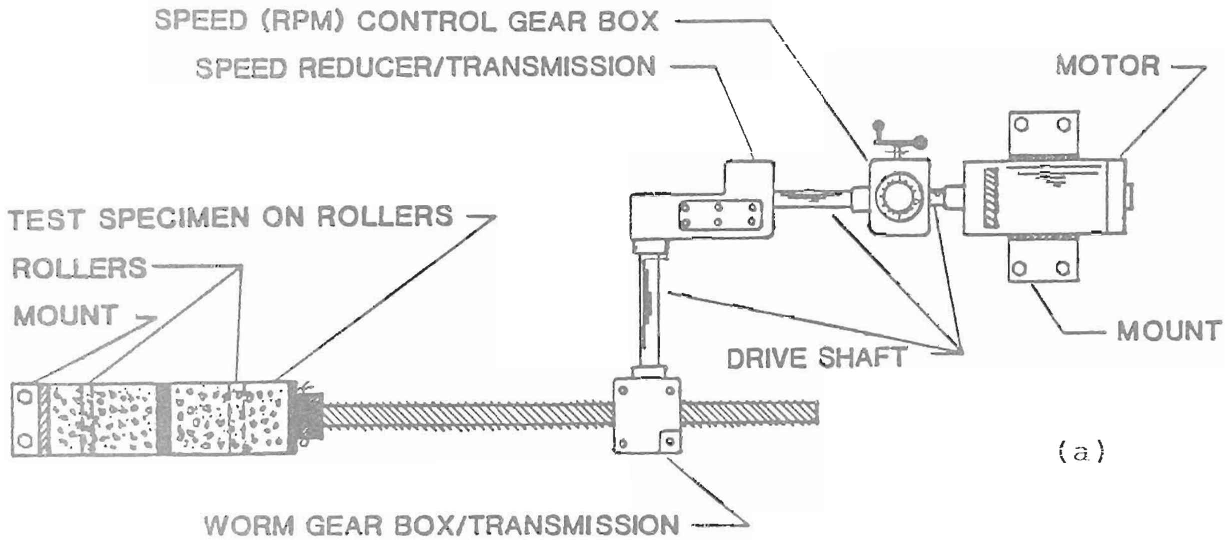
21. Remove the back and adjusting braces. Place the beam-plate assembly in the 77°F controlled room for 24 hours for the joint to cure.

22. After the curing period, transfer the beam-plate assembly to the desired test temperature environment for a period of at least 24 hours but not more than 7 days.

APPENDIX C

PROCEDURE FOR MOUNTING AND TESTING BEAMS FOR SLOW EXTENSION

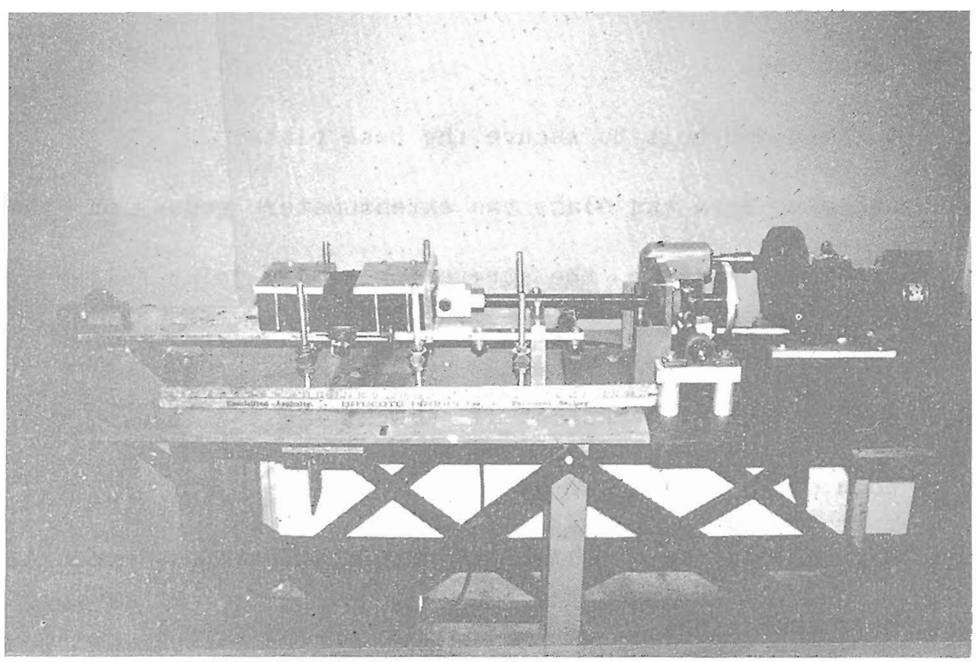
1. The beam-plate assembly and test apparatus have been in the testing temperature environment for a minimum period of 24 hours.
2. The clevis-connecting plate is attached to the front clamping plate and also to the leading aluminum base plate.
3. The beam-plate assembly is placed on the support rollers of the slow extension (1/8-inches per hour) apparatus. See Figure C1. The rollers have been adjusted so that the bolt connecting rod is normal and at mid-height to the face of the beam.
4. Attach the bolt connecting rod to the clevis plate and slide the base plates to receive the fixed-end bolt by turning the hand crank at the end of the bolt rod.
5. Tighten the fixed end bolt to secure the base plate.
6. Remove the holding bars and place two extensometer gages on the base plates so as to measure the stretching of the joint filler as it is loaded.
7. Use the hand crank to take out all slack from the loading system and then zero both dials of the gages.
8. Use the appropriate data sheet to record information concerning the joint and test conditions.
9. Start the test by energizing the adjustable speed drive motor. Record starting time and also times for subsequent readings of the dial gages. Note behavior and type of failure (adhesive or cohesive) of the joint filler.



(a)

TOP VIEW

TEST SYSTEM SCHEMATIC



(b)

Figure C1. Photograph of Slow Extension Test Apparatus

APPENDIX D

PROCEDURE FOR MOUNTING AND TESTING BEAMS

FOR REPEATED AND RAPID EXTENSIONS

1. The beam-plate assembly and test apparatus have been in the testing temperature environment for a minimum period of 24 hours.

2. Set the adjustable eccentricity of the cam to an amount slightly higher than the desired joint extension. The eccentricity is obtained by manually rotating the drive shaft and reading the dial gage placed over the cam. Rotate the cam so that the maximum eccentricity is towards the joint (to the left).

3. The beam-plate assembly is placed on the support rollers of the repeated extension (210 per minute) apparatus. The rollers have been adjusted so that the connecting rod will be normal and at mid-height to the face of the beam.

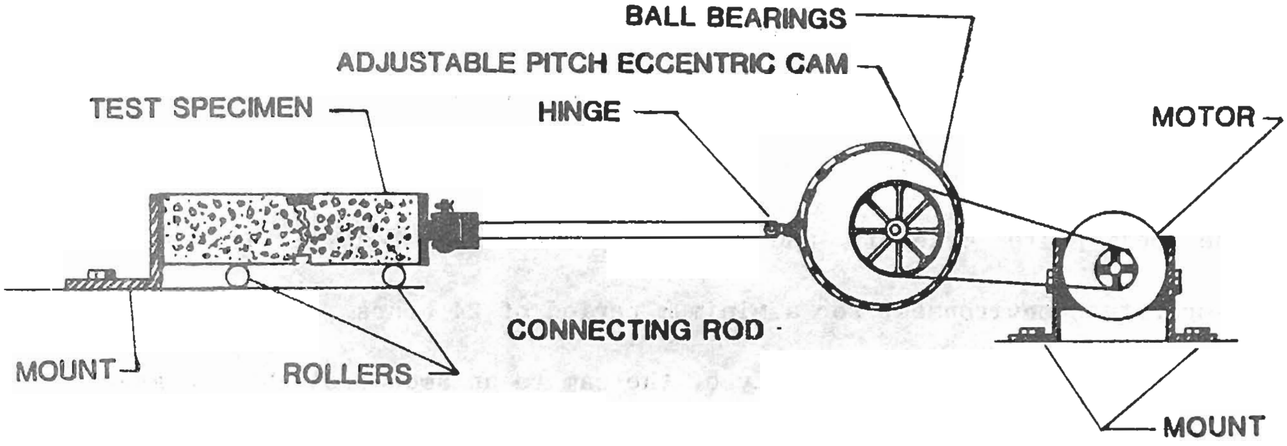
4. Bolt the loading plate at the end of the connecting rod to the aluminum base plate and also to the clamping plate.

5. Place the fixed-end bolt and nuts leaving a loose connection.

6. Remove the holding bars and attach the extensometers to measure movements between (a) the base plates, (b) the halves of the beam, and (c) the movement at the end of the beam (as shown in Figure D1).

7. Adjust and tighten the fixed-end bolts to effect a minimum opening or closing of the joint ($\pm$ 0.005 inch) as set from item 6 above.

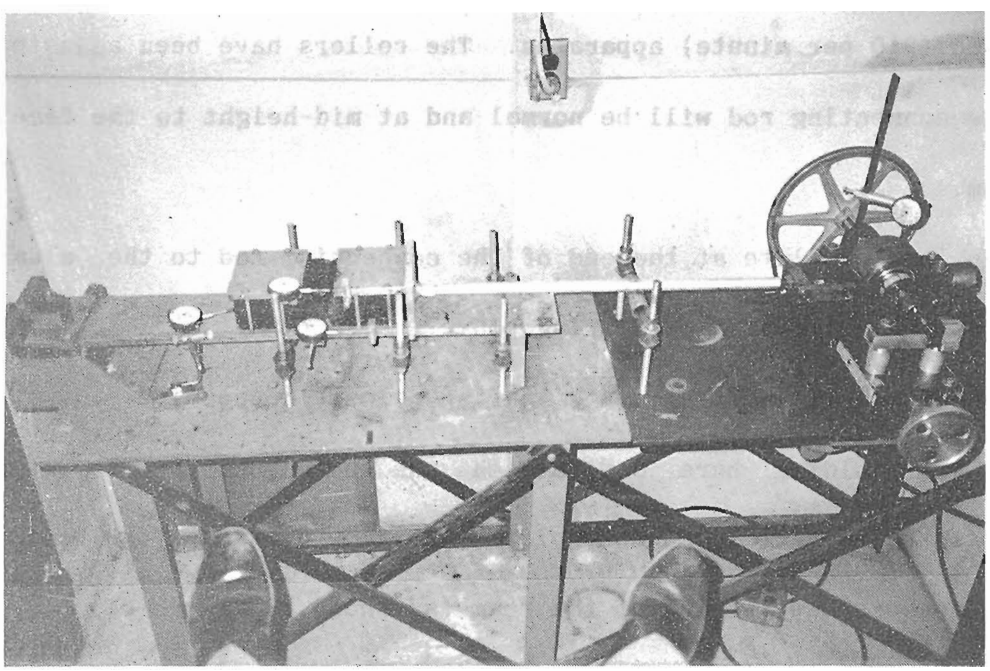
8. Slowly rotate the cam 3-5 times to check the amount of desired extension of the joint and also the movement of the rear end of the beam.



(a)

SIDE VIEW

TEST SYSTEM SCHEMATIC



(b)

Figure D1. Schematic and Photograph of Repeated and Rapid Extension Test Apparatus

9. Zero the three dials of the extensometer gages, two on the clamping plates at the top of the beam and one on the base plate, after rotating the cam so that the maximum eccentricity is away from the joint (to the right). In this position the first dynamic load will be one of compression which is extremely important when testing at cold temperatures. Also zero the revolution counter and dial gages.

10. Start the test by energizing the motor to drive the cam. Record starting time and also the time for subsequent readings of the three dial gages and revolution counter. Note behavior of type of crack failure (adhesive or cohesive) of the joint filler.

APPENDIX E

TEST DATA

Table E1. Effects of Temperature on the Cone Penetration Test for the Crack Fillers.

Table E2. Result of Exploratory Slow Extension Test at 32°F. Joints 0.2 Inch Wide and 0.5 Inch Deep.

Table E3. Effect of Shape Factor, W/D Ratio, on Extensibility of Joint Filler. Slow Extension. Joint Width of 0.30 Inch and Temperatures of 77° and 32°F.

TABLE E4. Resistance of Joint Fillers to Repeated Extensional Strains. Joints 0.5 x ± 0.375 Inch and Temperatures of 77° and 32°F.

TABLE E5. Result of Regression Analysis of Joint Fillers Under Repeated Loading at 77° and 32°F.

TABLE E1. EFFECTS OF TEMPERATURE ON THE CONE PENETRATION TEST FOR THE CRACK FILLERS

Temp. °F	Run	Filler Number										
		1	2	3a	3b	3c	3d	3e	3f	3g	4	5
32	1	32	a	6	28	0	21	64	3	14	0	b
	2	31		7	27	0	22	63	2	10	0	
	3	30		7	27	0	23	62	4	11	0	
	4									11		
	Avg	31c	a	7	27	0	22	63	3	12	—	b
77	1	137	a	51	76	47	48	141	84	34	35	b
	2	134		55	77	48	48	141	83	36	34	
	3	133		54	77	48	49	142	80	37	35	
	4	135										
	Avg	136c	a	53	77	48	48	141	82	36	35	b
140	1	186	a	168	158	b	b	200	b	b	b	b
	2	184		167	160			195				
	3	180		166	155			200				
	4							189	b	b	b	b
	Avg	183	a	167	158	b	b	196				

a - liquid
b - too soft, >250
c - due to bending of the surface

TABLE E2. RESULT OF EXPLORATORY SLOW EXTENSION TEST AT 32°F. JOINT 0.2 INCH WIDE AND 0.5 INCH DEEP					
	Elongation - Percent				
Filler Number	A	B	C	Avg	Rank
1	271	322		297a	3
2	93	59		76c	9
3a	331	453	504	429a	2
3b	201	291	200	231a	7
3c	510	381		446a	1
3d	267	227	317	270a	5
3e	215	384	290	296a	4
3f	249	240		245c	6
3g	134	150		142c	8
4	48	45	30	41c	10
5	47	24		36c	11

a - adhesive failure
c - cohesive failure

TABLE E3. EFFECT OF SHAPE FACTOR, W/D RATIO, ON EXTENSIBILITY OF JOINT FILLER. SLOW EXTENSION. JOINT WIDTH OF 0.3 INCH AND TEMPERATURES OF 77° and 32°F.

Joint Depth Inch	Test	Filler Number					
		1 Ext,%	3a Ext,%	3c Ext,%	3d Ext,%	3e Ext,%	3f Ext,%
Temperature 77°F							
0.5	A	86	121	126	76	50	184
	B	65	112	123	81	64	181
	Avg	75a	117a	124a	78a	57a	182c
0.6	A	65	107	140	65	59	166
	B	78	102	115	78	54	166
	Avg	72a	104a	128a	72a	56a	166a/c
0.7	A	99	99	129	70	108	269
	B	96	96	138	74	101	230
	Avg	98a	98a	134a	72a	104a	250a/c
Temperature 32°F							
0.5	A	322	562	324	230	350	340
	B	299	507	332	198	336	396
	Avg	310a	534a	328a	214a	343a	368c
0.6	A	317	367	346	202	398	255
	B	328	324	377	211	481	310
	C		440				
	Avg	322a	377a	361a	206a	440a	282c/a
0.7	A	469	354	308	235	520	306
	B	439	402	257	237	553	321
	C					623	
	Avg	454a	378a	282a	236a	565a	314c/a

a - adhesive failure
c - cohesive failure

TABLE E4. RESISTANCE OF JOINT FILLERS TO REPEATED EXTENSIONAL STRAINS. JOINTS 0.5 X ± 0.375 INCH AND TEMPERATURES OF 77° AND 32°F.

Filler No.	77°F			32°F		
	Repeated Extension		N_f to Failure	Repeated Extension		N_f to Failure
	d,in.,10^{-3}	ϵ 10^{-3}	10^3	d,in.,10^{-3}	ϵ 10^{-3}	x10^3
1	28.0	74.0	41	4.0	11.0	70.8
	30.0	83.0	54	6.0	16.0	96.8
	32.0	88.0	39	20.0	53.0	50.0
	41.0	117.0	12.4	46.0	123.0	6.0
	42.0	109.0	12.6	47.0	125.0	10.0
	50.0	111.0	10.2	65.0	173.0	1.0
	50.0	138.0	4.9	76.0	203.0	0.5
3a	28.0	66.0	23.0	6.0	16.0	92.0
	29.0	85.0	20.0	7.0	19.0	68.0
	* 41.0	119.0	22.4	15.0	40.0	2.4
	49.0	137.0	11.0	22.0	59.0	3.0
	50.0	148.0	10.0	23.0	61.0	6.0
				28.0	77.0	0.8
				36.0	96.0	1.2
				100.0		1.8 }*
				100.0		0.1 }*
3c	30.0	84.0	35.6	8.0	21.0	160
	33.0	92.0	32.7	10.0	27.0	270
	* 41.0	123.0	44	15.0	40.0	6 }*
	45.0	138.0	31	25.0	67.0	22.5
	50.0	148.0	20	30.0	80.0	20
				30.0	80.0	2.4
				40.0	107.0	13.5
				72.0	192.0	0.2
				74.0	197.0	2

*Outliers or did not fail

TABLE E4 - CONTINUED

Filler No.	77°F			32°F		
	Repeated Extension		**N_f to Failure**	**Repeated Extension**		**N_f to Failure**
	d,in.,10^{-3}	**ϵ 10^{-3}**	**10^3**	**d,in.,10^{-3}**	**ϵ 10^{-3}**	**x10^3**
3e	27.0	77.0	100.0	16.0	43.0	86.6*
	34.0	97.0	62.0	22.0	59.0	94.0*
	* 37.0	118.0	100.0	24.0	64.0	82.2*
	48.0	145.0	24.0	24.0	64.0	103.0*
	52.0	140.0	20.0	32.0	85.0	128.0*
				40.0	107.0	89.0*
				67.0	179.0	78.0*
				75.0	200.0	68.0*
				82.0	219.0	94.0*
3f	27.0	65.0	5.6	9.0	24.0	47.0
	30.0	84.0	4.0	9.0	24.0	71.0
				11.0	29.0	60.0
	41.0	111.0	4.2	20.0	53.0	36.0
	41.0	112.0	5.2	22.0	59.0	60.0
	45.0	127.0	2.4	22.0	59.0	60.0
	*- 51.0	124.0	5.4	30.0	80.0	30.0
				62.0	165.0	1.6
				65.0	173.0	1.5
				72.0	192.0	22.0)*

*Outlier or did not fail

TABLE E5. RESULT OF REGRESSION ANALYSIS OF JOINT FILLERS UNDER REPEATED LOADING AT 77°F AND 32°F.

$$\epsilon = Io + b \log N_f$$

Filler	n	$\overline{N}$ 10^3	ϵ 10^{-2}	Intercept (Io) Value 10^{-2}	Intercept (Io) t	Slope (b) Value	Slope (b) t	R^2
Temperature 77°F								
1	7	18.2	39.0	34.0	11.44	-0.0556	-8.00	0.927
3a	4	15.0	10.9	102.0	24.92	-0.2177	-22.26	0.996
3c	4	29.1	11.2	114.4	2.10	-0.2330	-1.88	0.640
3e	4	54.7	11.5	39.2	5.97	-0.0584	-4.24	0.900
3f	5	4.1	10.0	51.2	1.89	-0.1139	-1.53	0.437
Temperature 32°F								
1	7	10.0	10.1	42.8	14.90	-0.0818	-11.65	0.964
3a	7	6.0	5.26	17.3	5.81	-0.0318	-4.13	0.773
3c	8	10.1	9.64	32.5	6.34	-0.0565	-4.59	0.778
3e	9	**No failures for strains between 0.043 and 0.219**						
3f	9	23.1	7.4	43.0	11.50	-0.0814	-9.62	0.930

*The t values are all below a probability of 0.010

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